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1993

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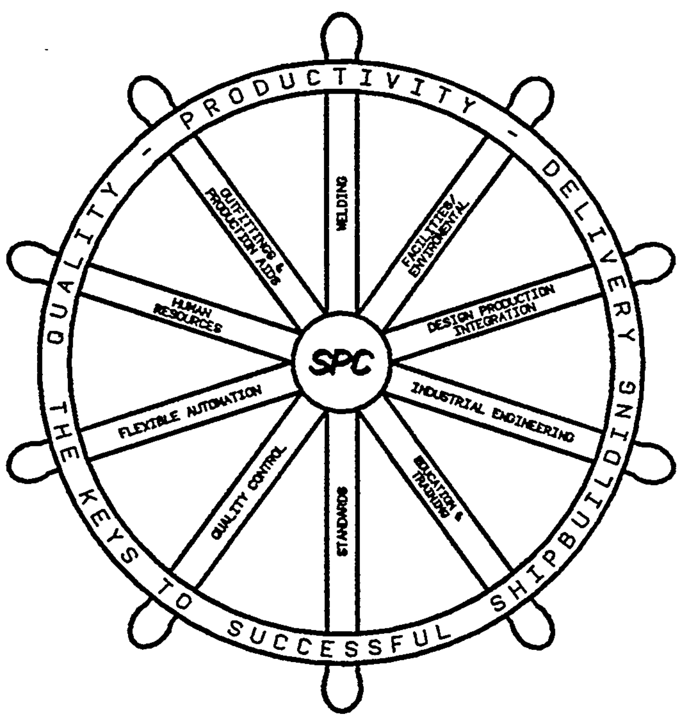

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1993 Ship Production Symposium
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Production Integration Via Solids Modeling

E. K. House DeVale (V) and J. R. Guilbert (V)-Newport News Shipbuilding

ABSTRACT

The integration of production planning within design has had a positive impact on both the design process and the design products. To effectively accomplish the integration, it is necessary to have a single 3-D product model of the ship, by which all design disciplines and construction planning personnel can effectively communicate.

The authors will address the significant changes this new approach has upon the design community and its deliverables. They will provide an overview of the enabling technologies and methods which facilitate construction-oriented feedback in the design phase. They will review additional benefits derived from the product model, such as eliminating physical mock-ups.

INTRODUCTION

The ship design/ construction industry has made significant improvements in efficiency over the last twenty years. The driving force was the fight for survival by individual yards in a shrinking market for new design, construction, and repair contracts. This condition has recently become even more critical for domestic yards as the U.S. Navy reduces ship acquisitions. This increased competition is forcing dramatic changes in the ship design and construction processes. An example of this trend is the use of computerized drafting tools to increase the accuracy and consistency of design products. On the construction side, modularizing large sections of vessels, and employing zone technology are streamlining the construction process, and reducing the amount of time required from keel-laying, to launch, to delivery. In both areas these methodologies are employed to drive down costs and increase efficiency. Generally within the industry, these innovations have been implemented through an isolated, rather than a coordinated effort.

During the last ten years industry leaders have recognized that a key to improving efficiency is to break down the barriers of isolation between the design and construction organizations. The term “concurrent engineering” is used to describe the incorporation of manufacturing intensive information into the design process. The aim is to reduce total cost and time associated with transforming design parts into manufacturable parts.

Before solids modeling systems were available, the integration of design and construction was limited to the examination of mature design products, and the attempt to repackage the data for production. Generally, feedback concerning these design deliverables in the design office was filtered or ignored, due to the high cost of reworking the design product. Despite significant construction input, many potential improvements in efficiency were not implemented because of the limitations of the medium. However, the availability of computer-based, solids modeling design systems is changing the paradigm. Properly applied solids modeling allows parts to be examined before committing them to drawings. This provides an opportunity for a producibility review prior to preparation of drawings or other manufacturing data. Thus, production integration via 3-D solids modeling facilitates addressing construction concerns within the design phase of a project.

Within the topic of production integration via solids modeling, there are numerous areas for discussion. This paper focuses on production integration in the design of SEAWOLF, SS(N)21. The SEAWOLF project is a significant case study because it is a large-scale project with a complex design. In order to give the necessary background on the medium used for the integration, the authors explain the basic characteristics of the 3-D, solids modeling system. Then, the paper discusses; (1) the use of 3-D, solids modeling for producibility, (2) the integration process in the SEAWOLF project, (3) the altered design deliverables, and (4) future applications.

3-D MODEL FEATURES

The major advantage of integrating production planning into the design phase is that manufacturing and construction concerns may be addressed prior to drawing development. In order to successfully perform this function, production planners must have access to the complete and current design. Completeness is critical because part interactions, accessibility, and interferences are the salient issues in production integration. A modeling system that reflects changes as they occur allows planners and designers to make decisions before change becomes too difficult. Traditional design tools and deliverables are inadequate for supporting such an integration. Solids modeling is the technology employed in the integration of production planning in the SEAWOLF design. In particular, the Newport News Shipbuilding (NNS) developed modeling system VIVID® is the tool selected to arrange structure, distributive systems, stowage, and machinery within the hull of SEAWOLF.

This solids modeling system was first employed in the modularization of SSN 756 in 1984. More recently, the system’s unique capabilities have been applied to many commercial, U.S. Navy and foreign navy projects. NNS is one of several companies in various industries using a 3-D modeling system to help integrate production concerns into the design process. In the shipbuilding and design industry both Bath Iron Works and Ingalls Shipbuilding experimented with a CAD/CAM model in the design and construction of the DDG-51 and the SA'ARs, respectively(l)(2). In the aircraft industry, Boeing is using a 3-D, computer aided design (CAD) environment and a design/build team concept for incorporating manufacturing concerns into the design of the 777 twinjet transport. These efforts are being employed to reduce costly errors, changes, and rework (3).

The requirement for access to the complete and current design is handled in this solids modeling system by storing parts for the entire vessel in a single database. Each physically significant part in the ship is modeled, topologically connected, and instanced in its ship location in the database. As a result of this comprehensiveness, designers and planners can perform their duties understanding the relationship each part has to the rest of the model. Understanding the design configuration for all the systems in a given area allows production planners to formulate a build strategy, document it within the model, and appraise parts for producibility before commission of the data to drawings. These steps result in superior quality source data for drawings, and maximized producibility of design parts.

Although the 3-D modeling system incorporates parts from the different disciplines, and illustrates their interactions and interferences, each part class is handled differently. Within this 3-D modeling system, the pipes, fittings, cables, wireways, ventilation, plates, holes, components, and beams are modeled, stored, and handled uniquely based on their type. In other words, functions or attributes are restricted to certain part types. The attributes of geometry are those characteristics that give the parts their physical identity. For example, the model creates and stores plates by material type, thickness, and square footage. Piping attributes include material type, inside and outside diameter, bend radii, and minimum design wall thickness. Each part class has a dedicated set of characteristics that the model stores, plus the basics such as part number and location within the ship. Functions permitted on the part classes match the characteristics of part geometry. For example, in ventilation modeling, sectioning bends allows a part bend to be approximated by a series of straight sections rather than a smooth curve. This function is permitted for ventilation because round, oval, and transition curves are fabricated using a section approximation. However, sectioning is not permitted for pipe since pipe bending results in a smooth, even radius curve. This translates the characteristics of the "real" part to a corresponding modeled part.

A majority of modeled parts derive their configurations from referencing components stored in a catalog. There are approximately fifty thousand components in the SEAWOLF design catalog, all of which have a "true" detailed representation. The catalog is an important feature because it allows a detailed representation of a part to be stored once and referenced many times within the model. If a component vendor changes a part's characteristics, this change can be reflected throughout the ship design by merely updating the catalog, rather than manually updating each reference. The accuracy of the SEAWOLF catalog and parts in general is critical because of the tightness of submarine design. The criterion for component modeling is to hold interface points to exact dimensions, and other surfaces in SEAWOLF to an accuracy that deviates less than 0.8 mm (1/32 in). The resulting images are complete and accurate, and provide the user with a true representation of the ship space upon which to base design and construction decisions.

Using a single database for the complete design also facilitates retrieving current information. Current in this case means up-to-the minute; there is no "down-time" for interfacing different segments of the design. Within this software system, the 3-D model can be modified interactively by many users at the same time. The users can be from different design disciplines or production planning. Capturing the changes as they are made allows other users to respond to the modifications in a real-time environment, thus reducing rework and invalid designs. The software also has a feature for reporting all parts that have changed since a given date, and parts impacted by those changes. This feature is useful in tracking design modifications. With approximately 453,000 parts modeled for SEAWOLF, managing concurrent changes is a critical task.

PRODUCIBILITY

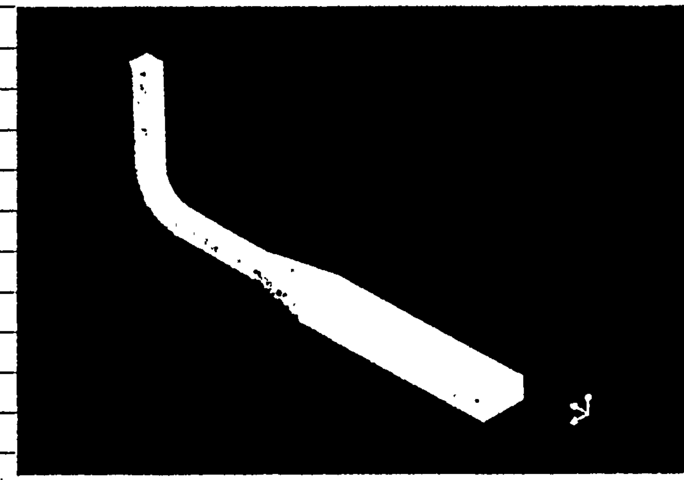
Addressing production planning concerns in the design phase of a project through 3-D modeling provides considerable benefits. In its application within the 3-D modeling, producibility is the ability to produce or manufacture a modeled part to specification. One goal of integrating production planners into the design process is the elimination of parts which cannot be fabricated from the model, and therefore the drawings, initial graphics exchange specification (IGES) data, and any other design products generated from the model. This filtering is achieved through several methods. In addition to incorporating production knowledge, the modeling system provides three separate features to eliminate unproducible parts from the model. They are tests, tools, and interactive feedback. In general, all of these features measure and/or accept parts based on producibility. Producibility testing depends on the part definition; the more specifically a part is defined, the more thoroughly it can be checked for producibility. Since each physically significant part for SEAWOLF is modeled, the producibility checks for parts in this design are rigorous.

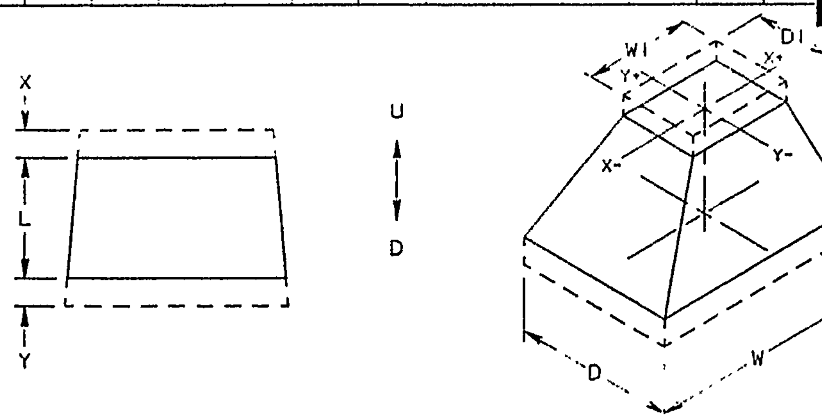
Tests

The software tests have encoded definitions of

SHAPE 18 (PROGRAMMING DATA)

FIND NO.	ASSY NO.	MATERIAL TYPE	MATERIAL THK	DATA W	D	W1	D1	L	V	X	X+/-	Y+/-				JOINTS OL/BUTT	AIR FLOW U/D	NO. CUT OUTS	NO. PCS	SEAMS P/W	REMARKS
VH01-42P20	41	AA	.05	7.00	3.00	4.90	3.00	7.65	1.53	-	+.06	-					D				
VH01-42P22	41	AA	.05	10.00	3.00	8.00	4.00	5.00	2.20	1.69	-1.00	-					D				
VH01-42P36	43	AA	.05	6.00	3.00	3.00	3.00	7.00	9.47	1.69	-1.50	+.50									
VH01-42P37	43	AA	.05	12.00	3.00	9.00	6.25	9.00	-	1.69	-1.00	+2.12									
VH01-42P39	43	AA	.05	9.00	3.00	8.00	4.00	6.68	-	1.50	-	+.25									
VH01-42P49	44	AA	.05	11.00	4.00	6.00	3.00	17.83	2.19	-	+2.50	-.26									
VH01-42P64	47	AA	.05	8.00	3.00	6.00	3.25	3.11	2.20	.40	-	-									
VH01-42P69	48	AA	.05	6.00	3.25	3.50	3.00	6.44	7.60	1.50	-.75	+.50									
VH01-42P90	51	AA	.05	13.00	5.50	9.00	4.00	5.00	2.19	-	-	-.80									
VH01-42P93	51	AA	.05	9.00	4.00	9.00	3.25	8.13	.78	1.69	-	-									
VH01-42P98.	52	AA	.05	9.00	3.25	7.00	3.00	6.04	-	-	+.93	-									
VH01-42P101	52	AA	.05	3.50	3.00	2.50	3.00	5.71	-	8.29	-	-									





TRANSITION - RECTANGLE

FIGURE 1

acceptance conditions for various part classes. An example of the utility of these tests can be shown in ventilation modeling for SEAWOLF. Traditional design agent ventilation drawings depict “runs” instead of individual ventilation parts. A traditional ventilation drawing shows point-to-point transits with no individual part definition. The SEAWOLF specifications dictate the development and issue of detailed ventilation parts on the drawings. Over 90% of SEAWOLF ventilation parts conform to a set of industry standard shapes. When modeling ventilation in the 3-D product modeling system the designer can automatically check for compliance with the standard shapes. The drawings translate the modeled ventilation into a list of discreet parameters needed to fabricate each ventilation part (Figure 1). This testing process has two major benefits: the first is fostering the use of standard ventilation shapes which maximize producibility, and cost effectiveness. The second benefit is the automatic selection of the most producible of the standard shapes. For conditions where multiple shapes may be used, the parameters for the most cost effective shape are calculated and transferred to a drawing sheet.

Tests are provided for other part classes as well. For example, piping design includes checks for normal connectivity, and bending machine compatibility (Figure 2). These tests prevent rework costs associated with drawing revisions and scrapped material. Cables,

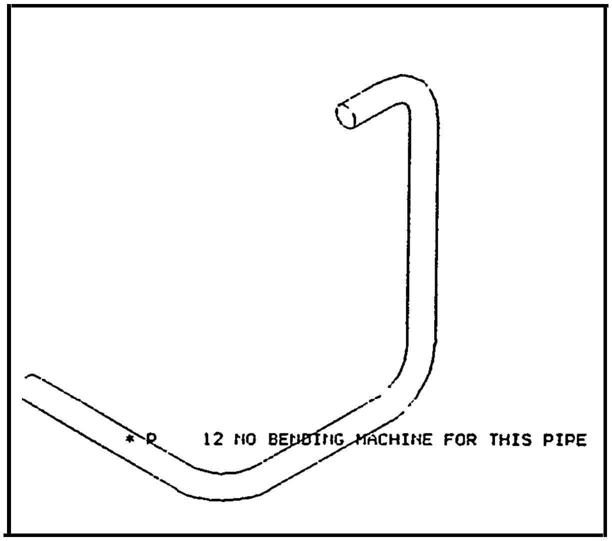
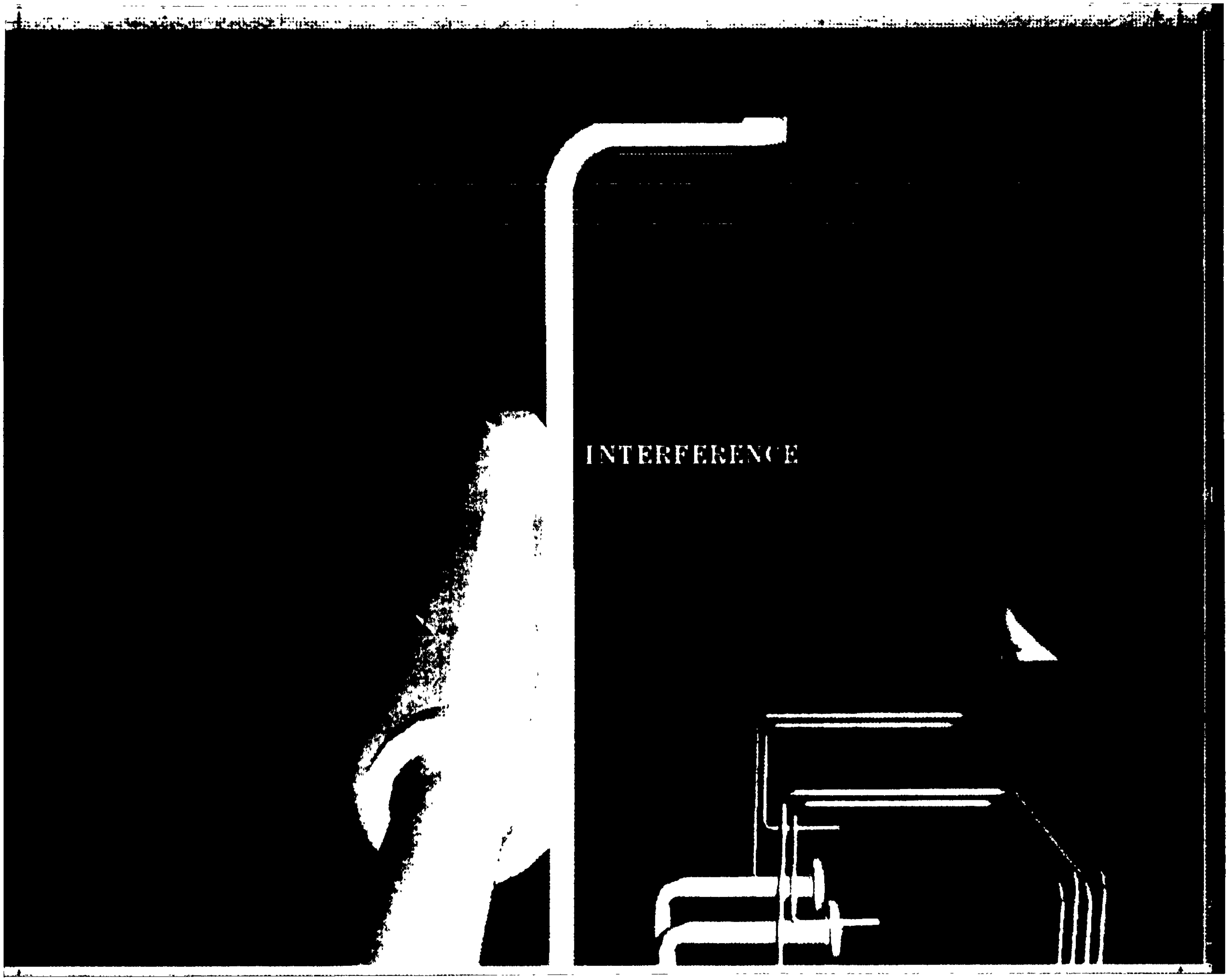


FIGURE 2

structure, and sheet metal have their own-specific tests, and the potential for designing new tests to match potential production limitations exists.

Tools

Tools are also important instruments for the designer to wield in determining if a designed part is producible. Unlike the tests which have embedded intelligence about acceptance conditions, tools are aides for the designer to use in evaluating the modeled parts. For example, the 3-D modeling system provides the designer the capability to grow parts and to perform interference analysis on grown and adjacent parts (Figure 3). The growth feature expands a part by a given amount. The interference analysis is an easily performed and accurate check for parts that physically occupy the same space, or encroach into access spaces needed for operation or maintenance. In submarine designs, noise clearances are an additional factor. The solids modeling system employs


INTERFERENCE

an expert system to identify noise interferences and to preserve shock excursion models.

In addition to the benefit these features provide for the designer, production planners use these same tools to identify instances of tight tolerances. By identifying areas of tight tolerance during design, they are able to relate to the builder, via construction drawings, where more accuracy in fabrication and/or installation is necessary. Providing this kind of detailed tolerancing data has only been possible since the advent of 3-D modeling technology. It is perceived that the net result will be a reduction in construction rework costs for correcting interferences as a result of tolerance stack-ups.

Interactive Feedback

The tools and tests described above operate after the part has been defined. The timing of interactive feedback is different; it happens while a part is being defined. Depending on the seriousness of the infraction, the system will either deny the user the ability to define a part, or simply display a warning message. On the least serious side, the system warns modelers if they duplicate part names while designing parts. The more serious interactive feedback is for infeasible geometry, such as a plate not defined on a plane, or an incompatible bend radius for pipe, ventilation or cables. The immediacy of the feedback allows the modeler to alter the part definition while still focused on the particular part. This again prevents the issuing of defective parts on drawings, and ultimately preventing rework in design and construction.

Interactive feedback, designer tools, and automatic tests work together to eliminate parts which cannot be fabricated from the model, and hence the design products. They are adapted to provide production-oriented guidelines, and are tailored to each specific part class. The result is lower rework costs associated with production due to the identification and correction of serious design flaws before committing the design to a drawing.

CONCURRENT DETAIL DESIGN AND DETAIL PLANNING

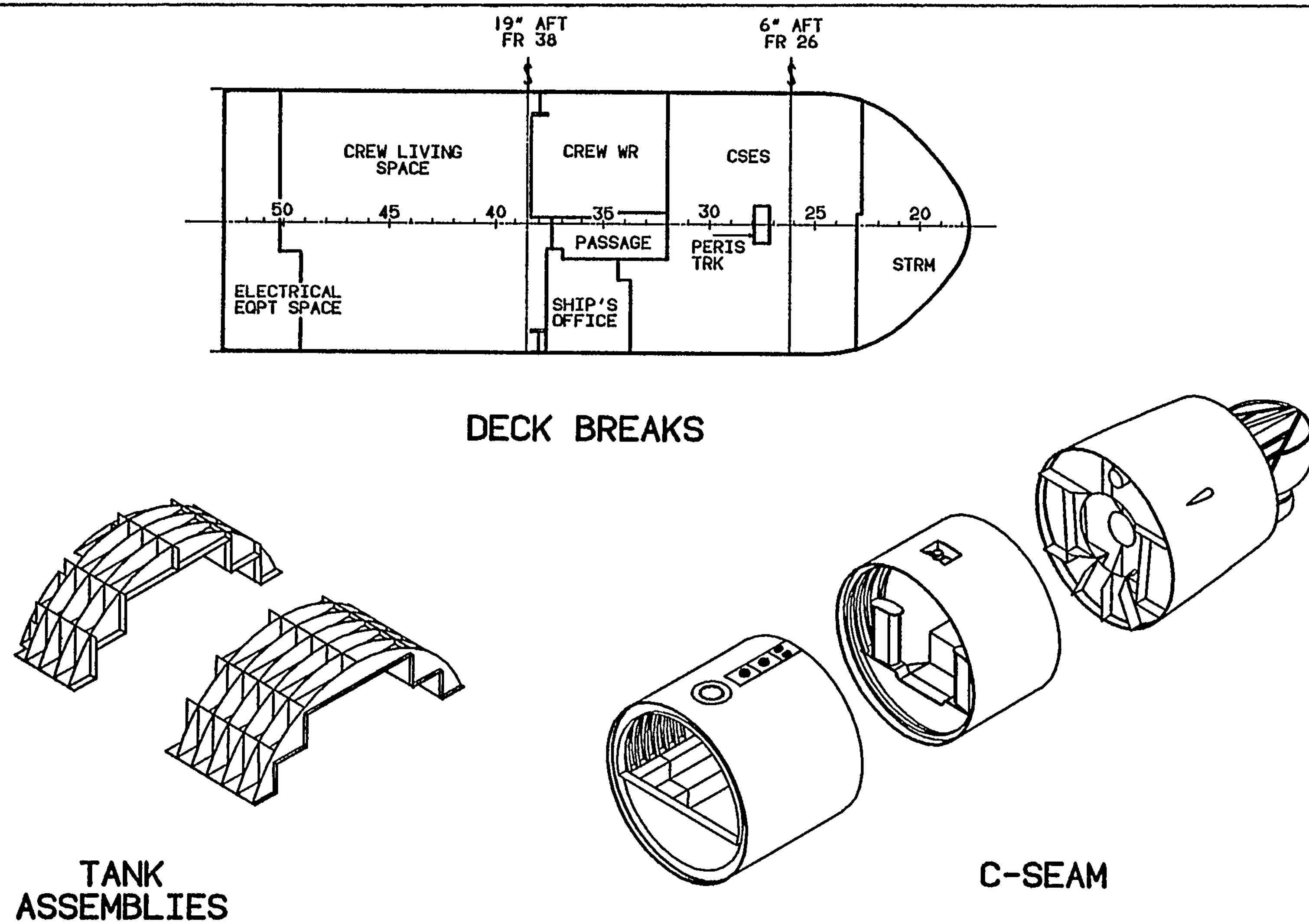
The shipyard’s most comprehensive use of solids modeling is as lead design yard (LDY) for the SEAWOLF class attack submarine. This role charges the LDY with the responsibility for detail design and arrangement of the forward compartment. This design effort provides the first large-scale opportunity to integrate production planning with design by the use of the community 3-D model. In contract design, the U. S. Navy established producibility requirements which dictate a design process which allows the design to be equally accessible to both designers and production personnel. The advantages of a computer modeling solution are further amplified by the detail design specifications, which dictate a design agent-developed construction plan, and corresponding product-oriented construction drawings, called sectional construction drawings (SCDS). In order to satisfy the specifications the LDY committed to model its part of the design completely within the solids modeling system, and to staff the design effort with a team of experienced shipbuilders from waterfront trades. The success of the effort depends on the ability to integrate the production planners into the design process, rather than relegating them to reviewing completed design products.

Contract Design

Integrating the production planners into the design process, and into the solids modeling community, began in contract design. Contract design spanned the time period of mid 1985 through early 1987. The first goal was a set of high-level decisions about the build strategy of the vessel. Fulfilling the program requirement for a modular construction building plan required identification of hullseams, deck breaks, and major structural tank assemblies, even as the parameters of the vessel were being finalized (Figure 4). The ability to make these decisions was facilitated by the planners' production experience, and by design images produced by the modeling system. The goal of the production team was to develop and document a build strategy that took maximum advantage of the assembly and outfitting of large structural elements prior to bringing those units to the ship proper. For this effort the computer system provided the structural planners with the ability to examine the structure, with the appropriate outfitting counterparts, and define large pre-outfitted hull, deck, and tank assemblies. Previously, this type of coordinated approach to planning both structure and outfitting was either difficult or impossible, due to the limitations of design materials. The solids modeling system's viewing features fostered a high level of confidence that the major elements of the construction plan, though aggressive, were attainable.

In addition to structural element definition, a similar effort was undertaken to define modules of large self-contained functional systems. The modules consisted of major components, piping, and cable generally located on common bedplates or platforms. Where the structural planning effort intended to streamline the erection sequence of the vessel, the effort to define "modules" was aimed at maximizing the installation, testing, and operation of the ship's functional systems away from the confines of the hull cylinders. While designers located major components and equipment within the hull, the planners and designers identified specific units of the geometry that were module candidates. The candidates were grouped together and documented in the model for the design community to see. The objective was to concentrate the arrangement of systems within the boundaries of modules to support common foundations, and off-hull system outfitting and testing (Figure 5).

Integrating construction planning into the design


19" AFT
FR 38
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CREW LIVING
SPACE
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CSES
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PASSAGE
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C-SEAM

FIGURE 4

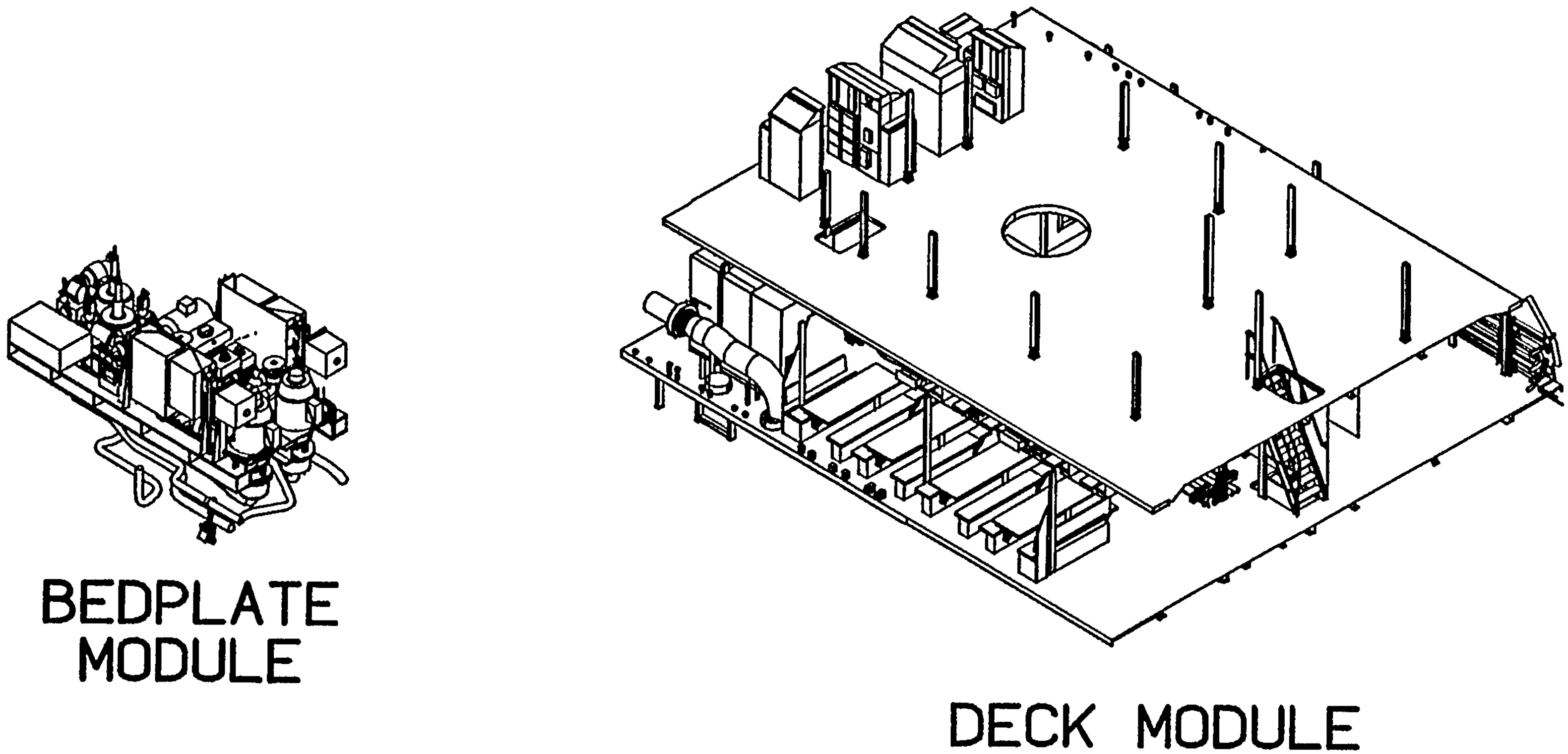

FIGURE 5

process resulted in the definition of the elements for an aggressive modular construction build strategy. Construction decisions such as circumferential seams and deck-breaks were recorded in the model to inform the design community, and to enhance producibility. The software's ability to incorporate and display planning decisions, and the overall construction strategy, reinforced the goal of a producible ship design. Performing this function in the early stages of a ship design, especially one as complex and as sequence critical as a nuclear-powered attack submarine, flushed out design production conflicts that are more costly to resolve at later stages of design or construction.

Detail Design

The relatively high-level decisions of contract design transitioned to fulfilling lead design yard responsibility on the detail design for SEAWOLF. One specification requirement of the detail design effort is the development of a detail construction plan. This plan consists of discreet work activities documented in a critical path management (CPM) network. The design data required to accomplish each of these modular construction activities are depicted on an SCD. Each SCD is a complete and comprehensive package of design data for the purposes of accomplishing fabrication, assembly, and installation of its respective modular construction activities (4). The CPM network documents the interrelations between the SCDs and establishes the construction sequence. As an aside, it also provides the schedule base-line to measure the performance of both the design agent and the builder(5). Due to specification requirements to issue construction-ready documents to the builder, the functional system configuration of the design is transformed into the units of modular construction depicted on SCDs.

SCDs are defined within the 3-D modeling system by construction planners on a piece-part basis. Each individual part in the model is examined by planning, and assigned to an SCD. This process occurs concurrently with design in order to have the maximum impact on the producibility of each part and its arrangement. The integration strategy for SCD development dictates that as the design for each compartment moves towards completion, the SCD boundaries are established. These boundaries are defined and documented by construction planners within the model. Essentially, this process is the development of a complete list of design parts to be contained on the SCD. This definition is performed based on specific criteria meant to enhance the constructibility of the design geometry. Examining the design geometry in its position within the modeled ship allows planners to visualize the installation of the final assembly of the particular product (Figure 6). In this application, the construction planners use the 3-D view features to analyze and eliminate loading interferences, to maximize favorable weld joint positions, and to generally prove the

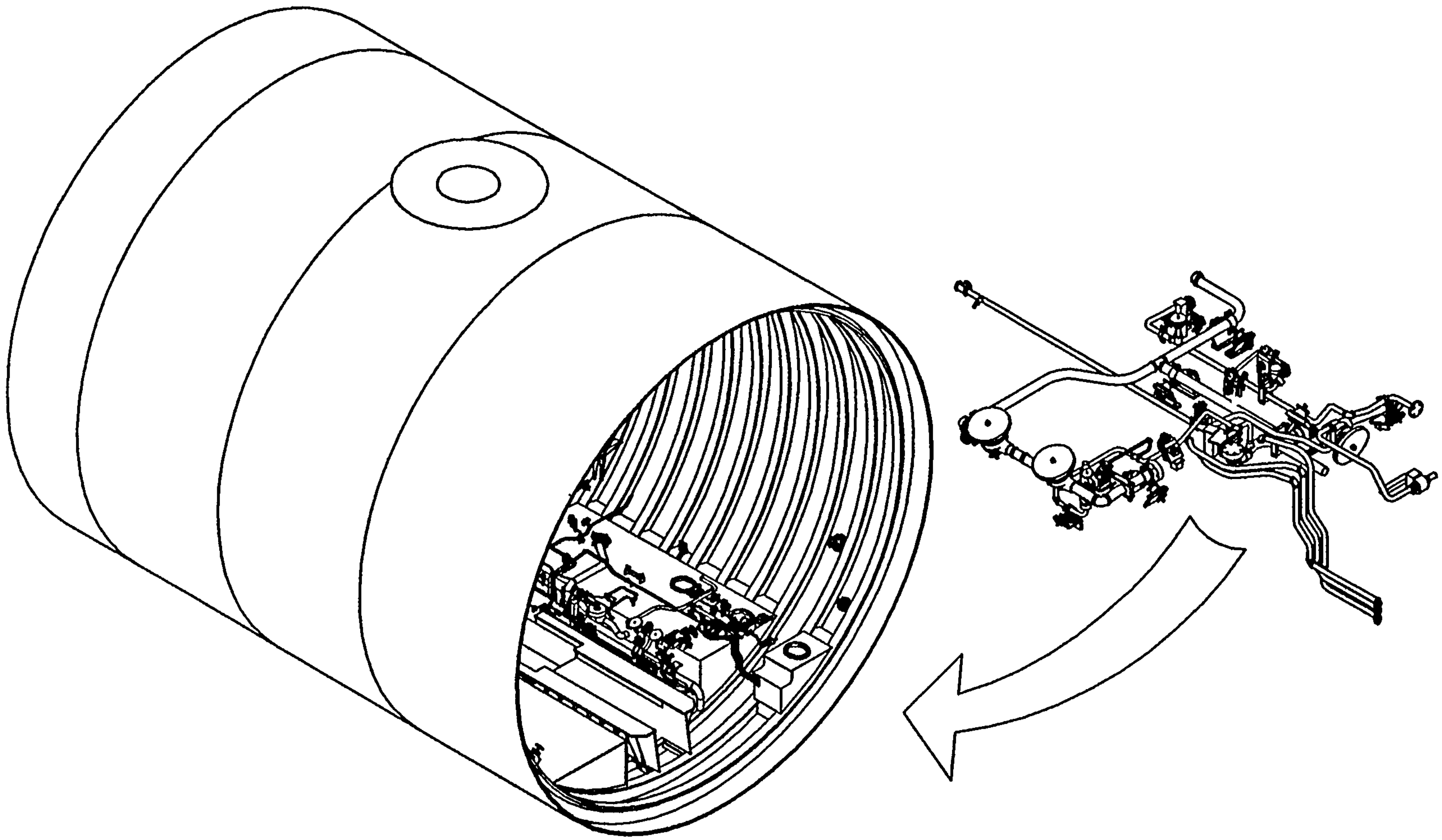

FIGURE 6

effectiveness of the design. SCD development often generates feedback to the design team that modifications are required to the geometry. The product of this initial planning phase is a complete list of parts for depiction on the SCD.

However, the SCD list does not satisfy all of the requirements for the drawing. The SCD must contain the fabrication and assembly data required to prepare the product for installation into the hull or module. Planning the manufacturing of pre-assemblies and assemblies for structural, piping, ventilation, and other outfitting products is critical to the effectiveness of the construction strategy. Modular construction strategies must maximize the assembly of the vessel's geometry outside the confines of the hull. In other words, the strategy must take advantage of assembly in shops and on platens prior to transferring those interim products to the ship proper. By viewing the previously defined SCD boundaries stored in the model, the planners can evaluate the most favorable assembly sequences for the parts. Evaluating the assembly sequence requires a thorough knowledge of accepted shop fabrication practices and standard facilities. The most producible part combinations are formed together and documented within the model to the most complete level of assembly possible (Figure 7). Developing the planning products in these two separate stages ensures a high level of producibility before committing the data to the drawing.

The product of the detail design planning process for SEAWOLF is a collection of product structures that document total content and optimum assembly/installation sequence for each SCD. Product structures are stored as a unique non-geometric part class within the model. The product structures are then electronically transmitted to the draftsman, whose job it is to develop the drawing with the content and relationships as documented by the construction planner. This process is accomplished without production of interim design materials such as internal blueprints. The development of the design, the contents of the construction drawings, and the CAD views that eventually become the drawings are derived from the model. The depth of integration of production and design is producing a rigorously evaluated modular construction strategy.

DESIGN PRODUCTS

Integrating production into design through the use of solids modeling software affects the design deliverables. The development of traditional design products such as drawings is changing significantly. New deliverables are being created, and some products are being curtailed or eliminated.

<u>Drawings</u>

A primary impact to design deliverables that solids modeling technology is fostering is the conversion of the drawings from a functional system configuration to a construction product configuration. 3-D modeling essentially made this transformation possible by

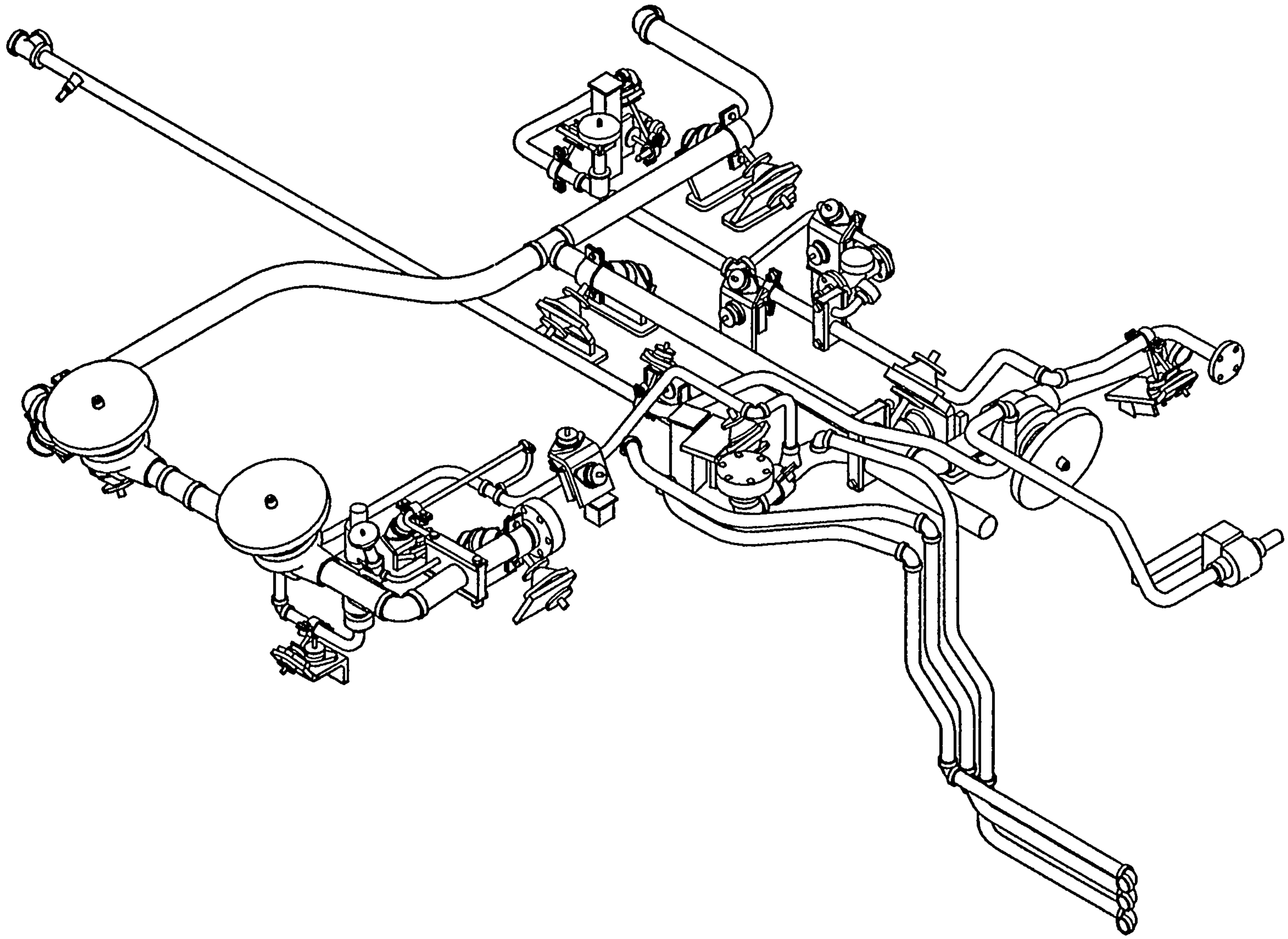

FIGURE 7

providing the planners with the ability to take apart the design and re-mold the data into the building blocks of the vessel, without the inefficiency of producing interim design documents. The SEAWOLF SCDs show that in addition to changing the form of the data, valuable information can be added to aid in construction. Typical design agent products do not provide all of the necessary dimensions and data needed for construction. Shipbuilders traditionally incur high value-added costs associated with design agent drawings. Traditional drawings require time-consuming interpretation by trades with less predictable results.

It is recognized on the SEAWOLF project that significant efficiencies could be gained by making the construction drawings sensitive to the trade's needs. The philosophy behind the SCD calls for limiting the included design data to the information needed for the corresponding construction activity. This information includes a bill-of-material that has defined and part-numbered material sources, a standard minimum tolerance for all operations, and improved accuracy of dimensioning and graphics. The accuracy of the design data is improving as a result of the use of CAD tools, that have a precision of several ten thousandths of an inch. Alterations are being made to the drawing graphics to compliment the change in drawing intent. Isometric views are added as the first view sheet of each SCD (Figure 8). This feature provides the trades with a way to visualize the extent of a particular job, thus reducing the amount of "start-up" time for each operation.

Another improvement in drawing graphics is matching the SCD drawing views to the actual position of the product in the corresponding construction stages. One example where this technique is particularly useful is the erection and outfitting of the platforms on SEAWOLF. The construction plan specifies the platform positions for each step in the process: it calls for the plate blanket and structure to be assembled, the underside of the deck to be outfitted, and then the inversion of the platform to outfit the top-side. The construction drawings that specify and correspond to each step of this sequence contain drawing views that match the dictated position of the platform (Figure 9). These views, as well as any other special views needed are specified by the construction planner, who developed the build strategy at the beginning of drawing development. The solids modeling system facilitates this construction-oriented approach to drawing graphics by allowing model viewing and drawing creation from any orientation. These views increase the capability of the design product, and ultimately the efficiency of the tradesman.

<u>Digital Design Data</u>

A new design product was introduced during the SEAWOLF project: digital design data. SEAWOLF design specifications dictate the development of standards for exchanging piping

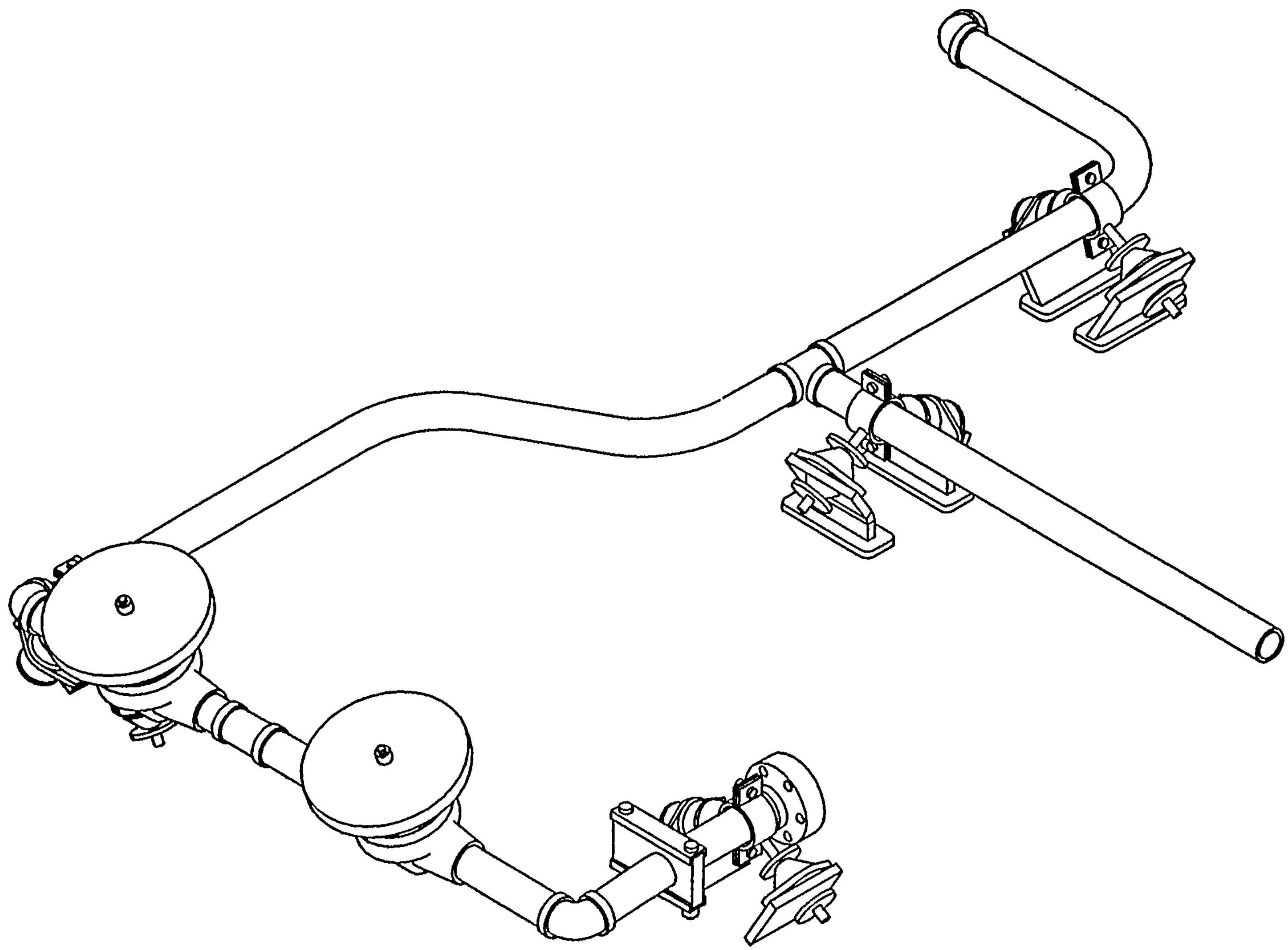

FIGURE 8

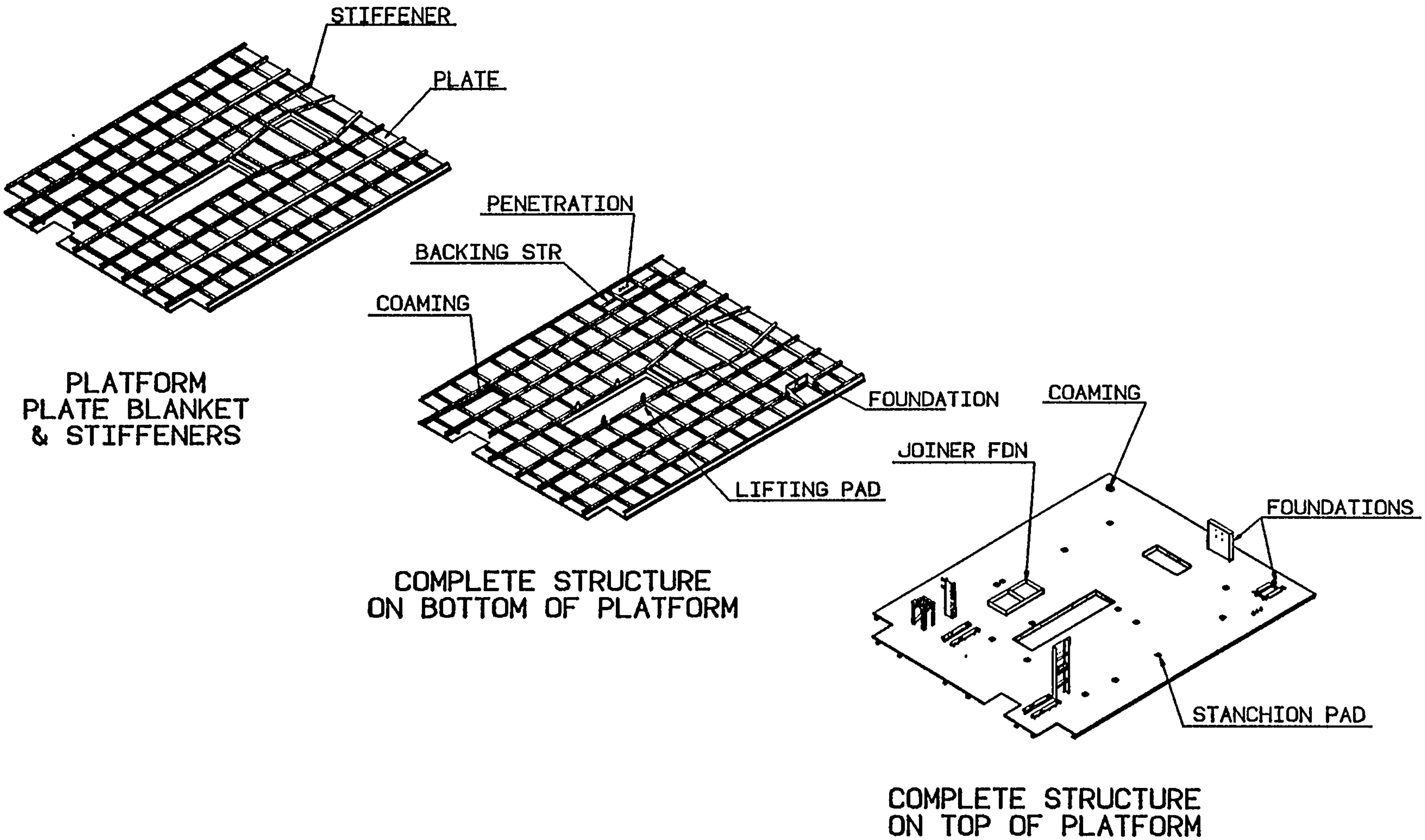
STIFFENER
PLATE
PLATFORM
PLATE BLANKET
& STIFFENERS
PENETRATION
BACKING STR
COAMING
FOUNDATION
LIFTING PAD
COMPLETE STRUCTURE
ON BOTTOM OF PLATFORM
COAMING
JOINER FDN
FOUNDATIONS
STANCHION PAD
COMPLETE STRUCTURE
ON TOP OF PLATFORM

FIGURE 9

digital product data between design agents and prospective builders. The exchange is accomplished by storing vital attributes about the design geometry on a magnetic tape in IGES format. The tapes are developed to be shipped and the stored design data retrieved on different machines. The portability of digital product data is critical to ensuring compatibility between different design agents and the builders. When using the 3-D product modeling system, the digital product data is a by-product of the modeling process; there is no extra effort required. The full potential of producing electronic data, in addition to or instead of paper drawings, has not been fully realized. Loading numerically controlled (NC) machines with electronic data extracted from the 3-D model could streamline the shipbuilding process. Perhaps the integration of computer aided manufacturing (CAM) will have the same impact on construction that CAD had on design.

Mock-Up

Potentially, one of the most visible modifications to the design product would be the elimination of a physical mock-up. Full scale mock-ups have been used as part of the submarine design process for many years. These mock-ups have become a primary tool in the validation process. The solids modeling system provides features for validating the model without constructing a physical mock-up. One of the major purposes of a mock-up is to facilitate the elimination of interferences. The interference analysis functions of the solids modeling system are proving to be almost perfectly effective in allocating space within the ship's arrangement, and interactively warning designers when there is an incursion. This feature has been refined to consider access and equipment cooling obstructions, up to and including the "swing" of locker doors and valve handles.

The second objective of the physical mock-up is slightly more difficult to satisfy using 3-D modeling. Physical mock-ups for submarine designs are used by the Navy's experienced submariners to evaluate operability, damage control, and maintenance attributes of the vessel's arrangement. The solids model representation does not always provide the same "hands-on," "view-from-station" objectives for personnel who must ensure mission capability and crew safety. However, recent improvements in view functions are winning over some skeptics. The advent of virtual reality technology may be the answer to addressing all of the concerns for operability. However, the U. S. Navy is satisfied with the SEAWOLF electronic model and is significantly curtailing the requirement for the forward-end physical mock-up. A detailed account of the SEAWOLF lead design yard's development and application of 3-D modeling as an elecltronic mock-up is contained in Tatum, et al's paper recently published (6).

FUTURE

Paperless Design

The final topic we will

discuss is the future applications of 3-D modeling and specifically the impacts on design products. Although not directly related to production planning integration, future enhancements to 3-D modeling could have significant impacts on design and manufacturing processes, and are therefore included in this paper. 3-D modeling has already had significant impacts on the design process and its products. Even though most agree that the capacity to generate, receive, and utilize electronic data exists, the essential products of the design effort are still paper drawings. The next frontier for design products is the elimination of most of the effort and cost associated with traditional drawing development and issue. The concept of paper-less design has many benefits for design agencies, but a few drawbacks for end-users of the design data. From a design agent's perspective, developing and generating purely electronic data eliminates reproduction costs and vault costs associated with storing paper drawings. Benefits for the end user obviously depend upon their ability to receive, manipulate, and distribute electronic data throughout their manufacturing processes. Unfortunately, end-user ability can vary from virtually no capacity to handle electronic data, to the ability to directly feed design data to NC machines. Many companies are discovering that paper is an expensive and cumbersome method of communicating design data. Using a CAD to CAM electronic link reduces local product costs, and reduces errors. Perhaps the most important objective of a paperless design is the speed at which products can move from a graphics terminal to a manufacturing shop. The most successful examples of this so far have been in the automobile industry, specifically Ford Motor Company. Ford is changing the concept of a drawing by utilizing data and minimizing the amount of dimensioning and other traditional design data contained in the CAD model (7).

A further innovation would provide an electronic copy of the solids model representation of a design to shipbuilders. In addition to eliminating the time and expense of drawing production for the design agent, this concept also has potential benefits for the builders. Chief among these benefits is the ability to customize the extraction of manufacturing data from the product model. Selecting manufacturing data by attributes such as material or other common traits allows tighter control of shop work loads, and greater efficiency through batch manufacturing. The design data are in a format that is conducive to generation of NC data, but can also be used to generate paper drawings for the production of assembly/installation sketches, and for generating design data to give to subcontractors. The extraction of the 453,000 parts from the SEAWOLF database could be accomplished with today's technology. However, there are significant issues to be addressed regarding an industry standard to ensure compatibility between companies for the elements of such data. A joint industry-government committee is currently addressing such issues and expects to have a usable product by late 1994. Overall, there is a significant amount of inertia in the design/manufacturing industry that will have to be overcome before exchange of entire "models" becomes a reality.

Virtual Reality

Another consideration for future development is the emerging technology called virtual reality, or cyberspace. Research is currently underway for several forms of virtual reality. The category of partial immersion appears to be the most likely candidate for use in the shipbuilding industry. Partial immersion equipment usually consists of a helmet and gloves. A virtual reality helmet uses micro-screen technology to display stereoscopic visual images in front of a user's eyes. These images are generated in such a manner that a user "feelsl" like he or she is inside the model. The computer that generates the visual images updates the displays to accurately portray what the user sees, accounting for head motion and "virtual movement" throughout the model. A virtual reality glove could be integrated into the system to sense the hand motions of the user. The glove would allow the user to interact with the objects in the model. Potentially, the glove could allow the user to touch, move, change, react to, or cause reactions in objects.

With the technology available today, images of complex models cannot be generated and displayed quickly enough to provide a reasonable simulation. This results in jerky transitions between views of even relatively simple models. Rapid advances in microprocessor technology may soon make available computer systems with the power required to implement such a system. Until that time the challenge of providing images which realistically capture real-time motion in a complex model remains.

Assuming that performance improves and the cost is reasonable, virtual reality could be a useful tool in production planning. The most obvious benefit is increased visualization. The VIVID ® system already allows single views from the vantage point of a human in the model. These views can be shown in sequence to create an illusion of walking through the model. Virtual reality would take this capability a step further and allow a user to determine path and view as they are walking through the model. The image would appear to be three dimensional. Currently,, production planning rarely uses the human vantage point feature, due to the set up time needed for each view. Instead, production planning manipulates views which show an outside the model representation, to evaluate construction processes. Operating in a virtual reality environment would be more interactive and intuitive, since the views are not pre-determined, are generated in real-time, and are from a human vantage point. Evaluating component loading sequence and loading paths would be as simple as "picking-up" the component(s) and moving it around the model.

The technology will have an impact on how aggressively and how detailed planning organizations are willing to direct production. Current technology limitations produce an uncertainty between planning and production. Using virtual reality technology production planners could simulate complex processes and decrease the uncertainty. Application of this technology would also facilitate greater certainty in predicting each step in an installation of a piece-part or maintenance of a component. For many situations this level of detail is not necessary. However, there are some processes where every detail and every step is practiced and monitored. Operations such as overhauling nuclear components or repairing orbiting satellites could be practiced by using the virtual reality simulation with less expense and effort than building a physical replica. Development and use of such technology will have far reaching effects on planning, and therefore management of complex processes.

SUMMARY

The advent of 3-D modeling technology has been the most significant contributor to the success of integrating production and design. The LDY's decision to design the forward end of SEAWOLF completely within the product modeling system demonstrates that a reformation of basic design agent deliverables and the inclusion of manufacturing intensive data in the design is attainable. Using the 3-D modeling system for SEAWOLF also facilitates the evolution of design deliverables from strictly paper and physical products to electronic products, saving both cost and schedule. There remain, however, many more cost and efficiency improving innovations that can be derived from and used in conjunction with 3-D modeling. Future submarine and surface ship designs will certainly take advantage of model technology and production planning integration. The application of this concept will expand as industry focuses on improving quality and driving down costs in order to stay competitive in today's market.

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